Cryogenic Summary - Testing D2L101 in MAGCOOL

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10/3/02 Rev.

- Operating Summary
- System Overview
- Features for Bay C
- Cooldown to 100 K
- Cooldown to 6 K
- Test Condition – 1.4 atm, 4.6 K (liquid cool)
- Quench Handling
- Test Condition – 12 atm, 4.5 K (force flow)
- Summary

Operating Summary

- 3/28-30 Cooldown - 300 to 100 K
- 3/31 Cooldown - 100 to 6 K
- 4/2 Reach 6 K, cold check, switch to liquid cool
- 4/3–5 Test D2 in liquid helium
- 4/6–7 D2 drift to ~40 K over weekend
- 4/8 Cool D2 to liquid cool
- 4/9-10 Test D2 in liquid helium
- 4/10 Switch to force flow cooling
- 4/11-12 Test D2 via force flow cooling
- 4/13-14 D2 drift to ~40 K over weekend
- 4/15-16 Cool D2 to liquid cool
- 4/17-18 Test D2 in liquid helium
- 4/18 Switch to force flow cooling
- 4/19 Test D2 via force flow cooling

Test Conditions

- Liquid helium cooling

  1.4 atm & 4.6 K

- Force flow cooling

  12 atm, 4.5 K & 60 g/s

Tests Performed - D2L101

- 1st test group (liquid cool),
  - Shut off - 1000 A (4/3)
  - Strip Heater - 2000 A (4/3)
  - Strip Heater - 4000 A (4/4)
  - 1st quench – 6309 A (4/4)
  - 2nd quench – 6877 A (4/5)
  - 3rd quench – 5862 A (4/5)
- Over the weekend, D2 drifted to ~ 40 K. 4/8 cool D2 to 4.5 K. 4/9 reach test condition.
- 2nd test group (liquid cool),
  - 1st quench - 5926 A (4/9)
  - 2nd quench - 5882 A (4/10)
  - 3rd quench - 6027 A (4/10)
- Switch to force flow cooling to investigate magnet behavior 4/10

Tests Performed - D2L101

- 3st test group (forced flow cooling ~ 4.5 K),
  - 1st quench – 7490 A (4/11)
  - Strip Heater – 4000 A (4/11) (-) bus also quench
  - Strip Heater – 4000 A (4/11) (-) bus also quench
  - 2nd quench - 6762 A (4/12)
  - 3rd quench - 6948 A (4/12)
- Over the weekend, D2 drifted to ~ 40 K. 4/16 cool D2 to 4.5 K. 4/17 reach test condition.
- 4th test group (liquid cool ~ 4.6 K),
  - Shut off – 1000 A (4/17)
  - 1st quench – 5868 A* (4/17) (+) flow controller malfunction but does not effect magnet quench.
  - 2nd quench – 6418 A (4/17)
  - 3rd quench - 6657 A (4/18)
  - 4th quench - 6566 A (4/18)

  * May have introduced some heat to D2 40 min. prior to ramping.

Tests Performed - D2L101

- Switch to force flow cooling to investigate magnet behavior 4/18

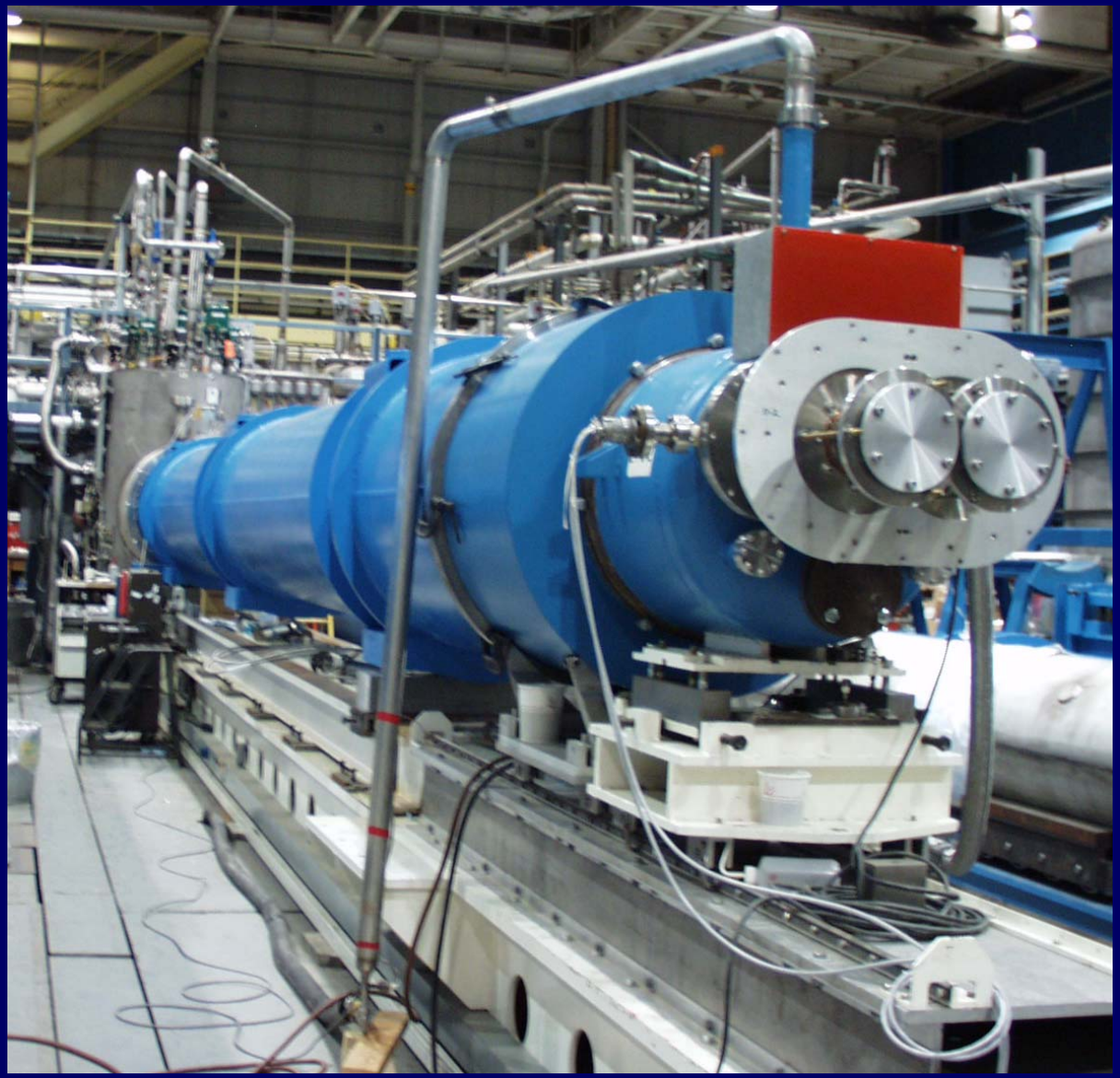
- 5th test group (forced flow cooling ~ 4.5 K),
  - 1st quench – 5700 A* (4/19) (+) bus quench
  - 2nd quench – 5523 A** (4/19) (+) bus quench

  * Probably due to bad flow controller, insufficient cooling above 4000A

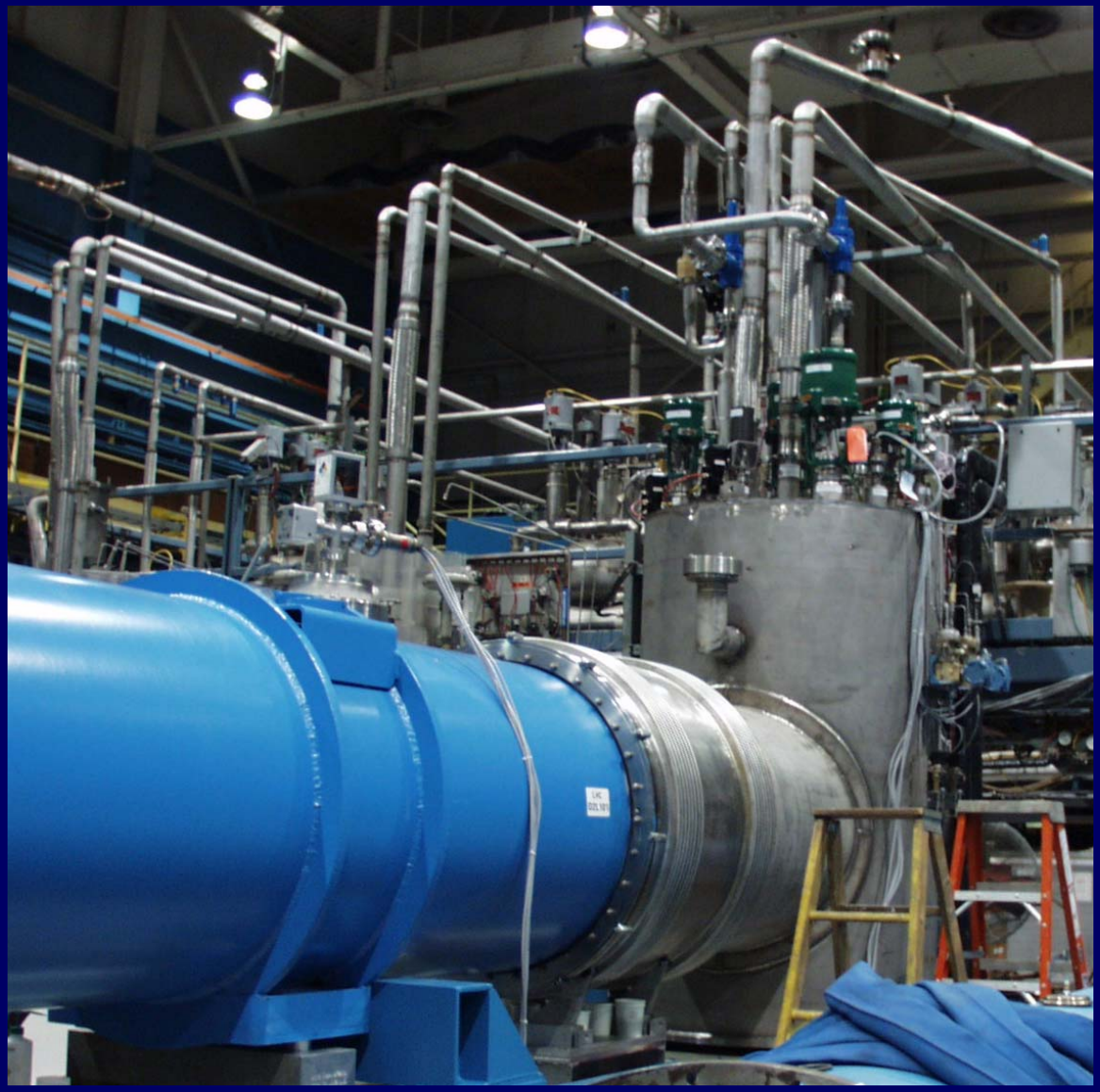
  ** Try to open by-pass valve at 1800 A to enhance bus cooing, unable to prevent bus from quenching

- Conclude 1st test run (4/19)

D2 on Test Bay viewed from End Can



D2 with Feed Can in Bay C



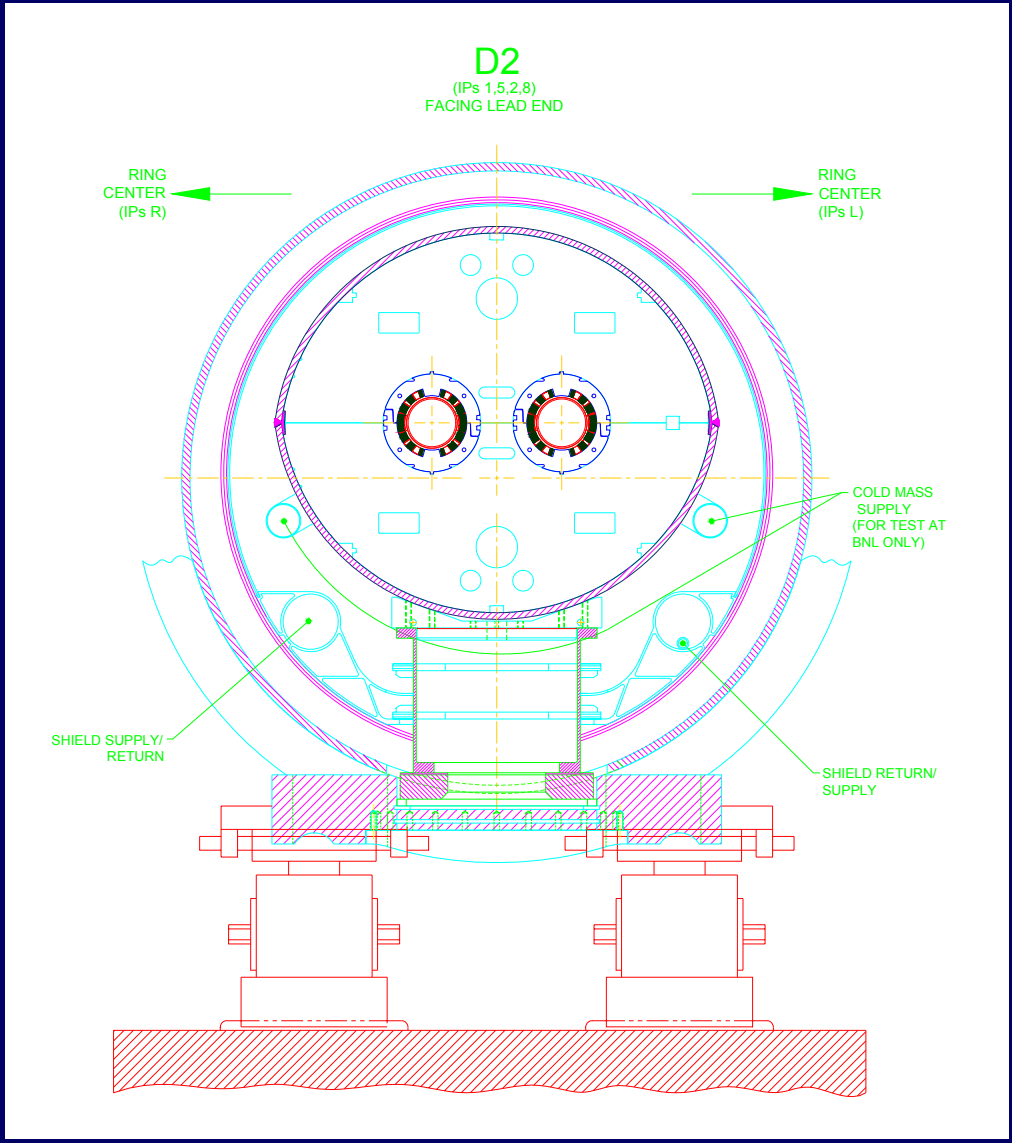
Features for Bay C Feed Can

- Accommodate 914 mm diameter cryostat
- Two warm bore tubes
- Control valves for cooldown, liquid fill, flow by-pass and quench venting
- Instrumented with pressure transducers, temperature sensors and flowmeters
- 4.6 K liquid helium cool
- Four 7500 A leads
- Slope adjustable test bay

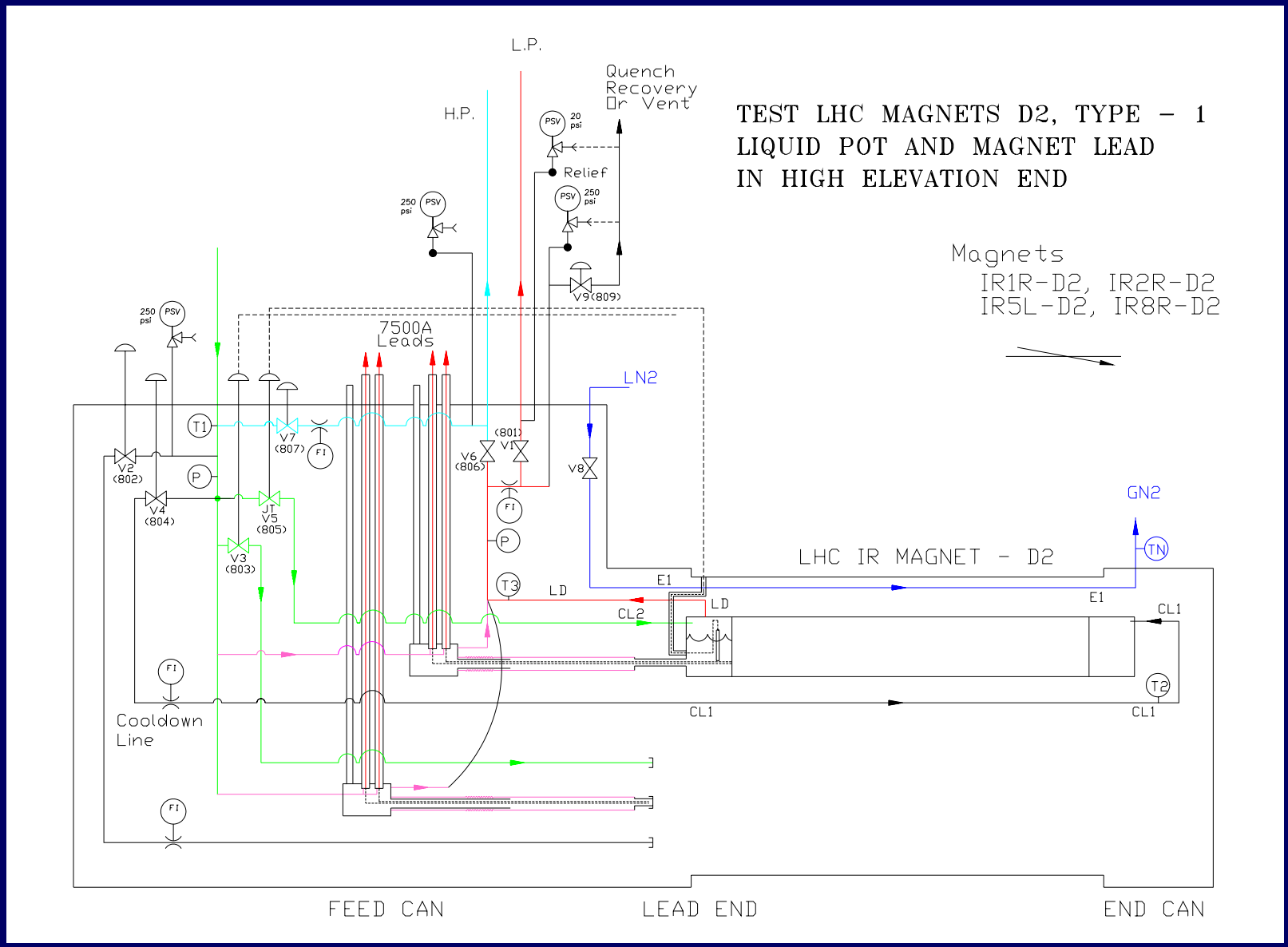
Specific for D2L101

- Test Bay kept horizontally
- JT Feed and Boil-off return in Lead End (Feed End side)
- Cooldown feed from the Non-lead End
- Warm bore capped
- Extra two leads for D3 capped
- One level probe in the non-lead end is known to malfunction prior to test

Sectional View of the D2 Magnet



Flow diagram for D2 with Feed Can and End Can



Cooling Flow

- 300 to 100 K
  - MAGCOOL Cooldown I Supply → Feed Can → CL1
  - → End Can → D2 → MAGCOOL CD I Return
- 100 to 6 K (and Force Flow cooling)
  - Refrigerator → MAGCOOL Low Temp Supply →
  - Feed Can → CL1 → End Can → D2 → MAGCOOL L. T. → Refrigerator Return
- Liquid Cool at 4.6 K
  - Refrigerator → L. T. Supply → Feed Can
  - -- → JT valve CL3 → D2 → Low Pressure Return -- →
  - -- → By pass flow → MAGCOOL Normal Return -- →
  - --- → Refrigerator

Cooldown from 300 – 100 K for D2

- Cooldown rate
  - ~ 3.3 K/hr between 300 and 220 K with 45 g/s, dT ~ 50 K
  - ~ 4.8 K/hr between 220 and 108 K, Fast Cooldown started at 180 K
- Cooldown time from 300 to 100 K ~ 54 hours

Cooldown from 100 – 6 K for D2

- Cooldown (100 to 6 K in ~ 24 hours)

  between 100 and 50 K ~ 10 hours or 5 K/hr

  between 50 and 20 K ~ 3 hours or 10 K/hr

  between 20 and 10 K ~ 6 hours or 1.5 K/hr

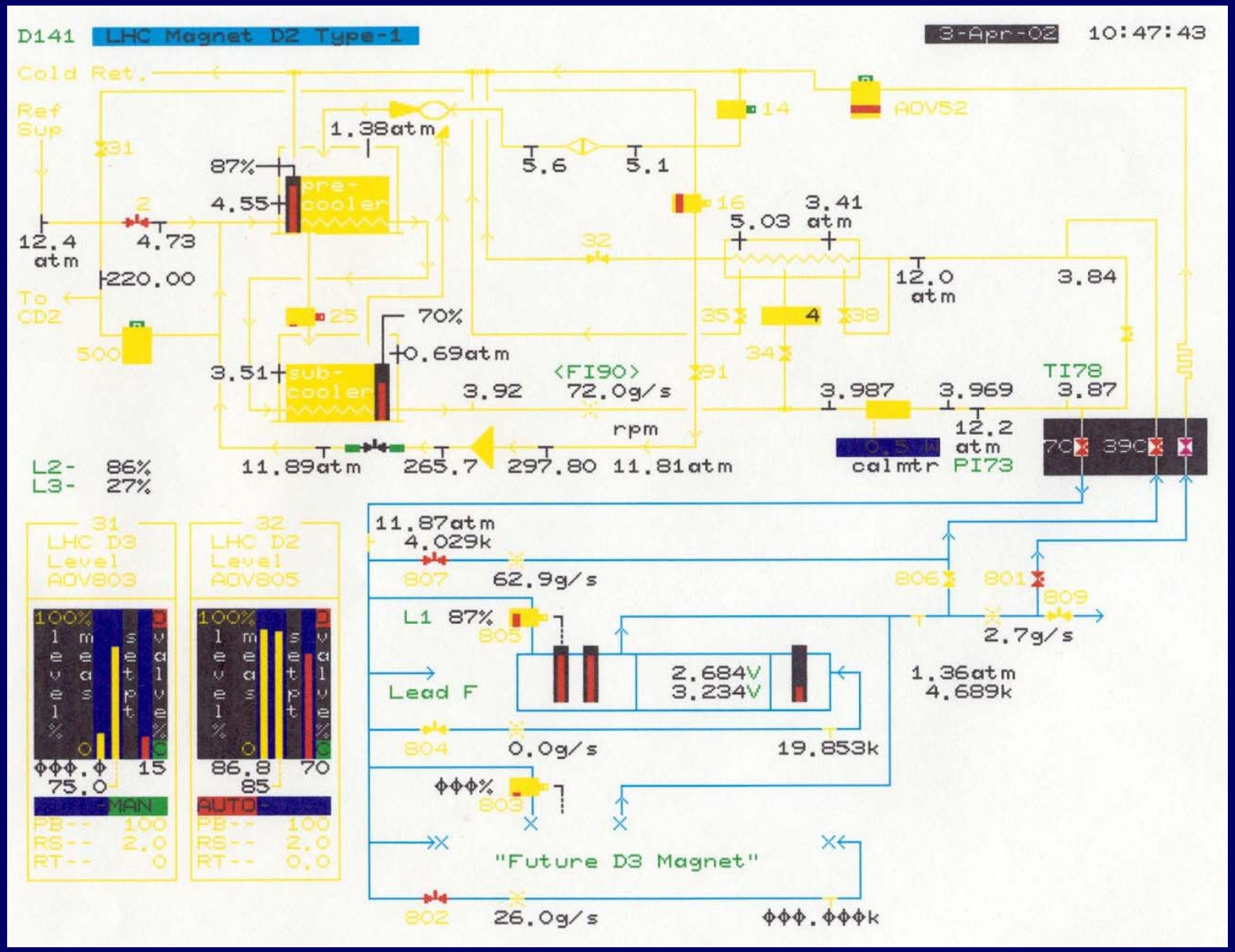
  between 10 and 6 K ~ 4 hours or 1 K/ hr

Switch to Liquid Cool – 12 atm, 6 K to 1.4 atm, 4.6 K

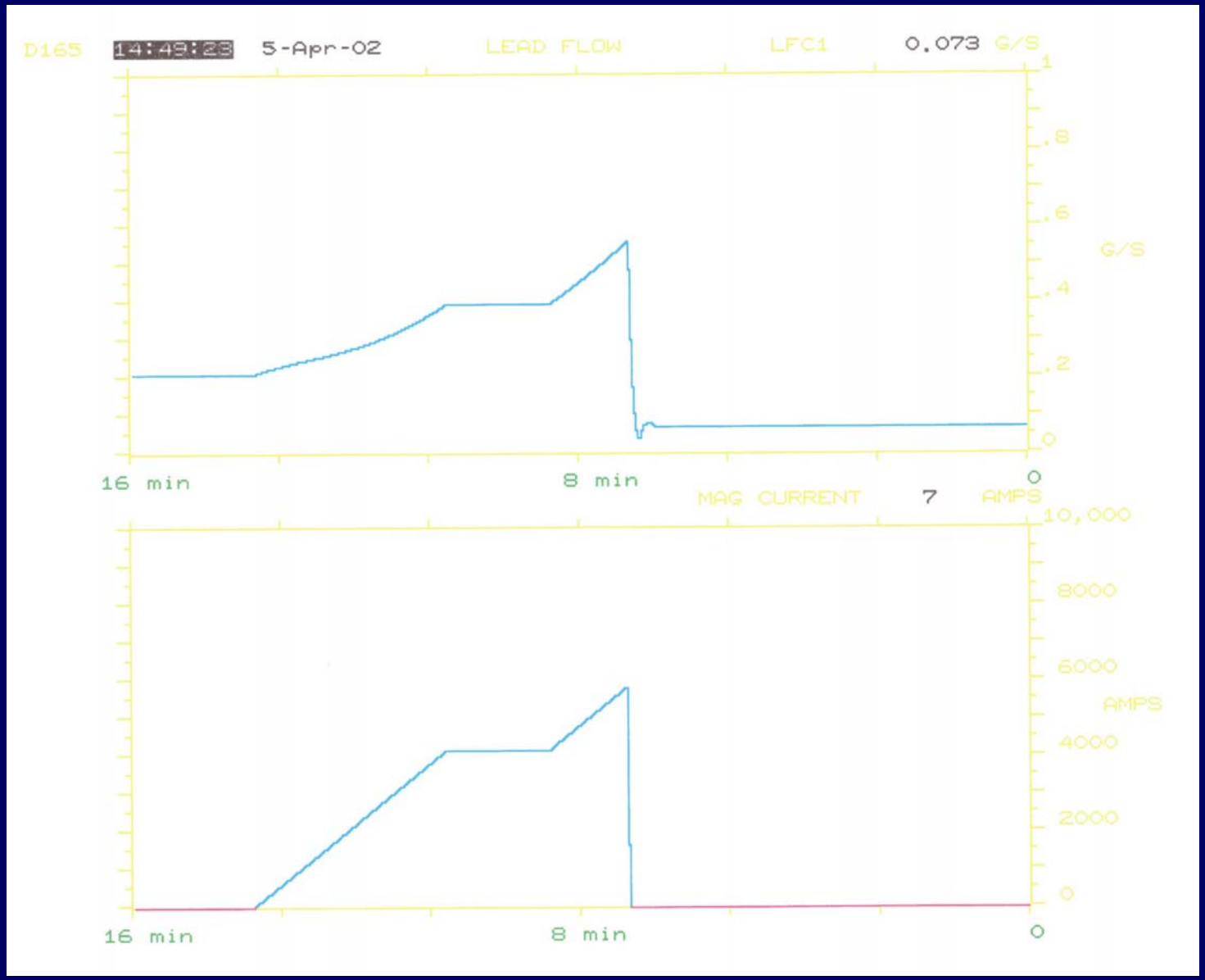
- Switch to JT level control in ~ 3hours, by
  - Precool low pressure return line,
  - open flow by-pass valve,
  - close cooldown valve,
  - vent helium to warm return
  - and other operations

- At test condition,
  - Inlet to JT is 12 atm and 4.0 K (~87% liquid)
  - D2 is maintained at 1.35 atm or 4.6 K
  - J-T flow ~3 g/s - level 85% 4/4 to
    ~5 g/s - level 95% 4/5
    Sign of liquid carry to return line at 95% level

Operating condition for D2 – liquid cool



Lead flow vs current during ramping of D2 quenched at 5368 A



Effect of Quench on Cryogenic System

- Magnetic stored energy of two coils, two times 1/2 L I^2, released into cooling helium
- Pressure and temperature in helium flow increase
- Vent cold helium to prevent over pressure
- Recovery time depends on energy released
  - ~ 6 hours for for a 6000 A quench

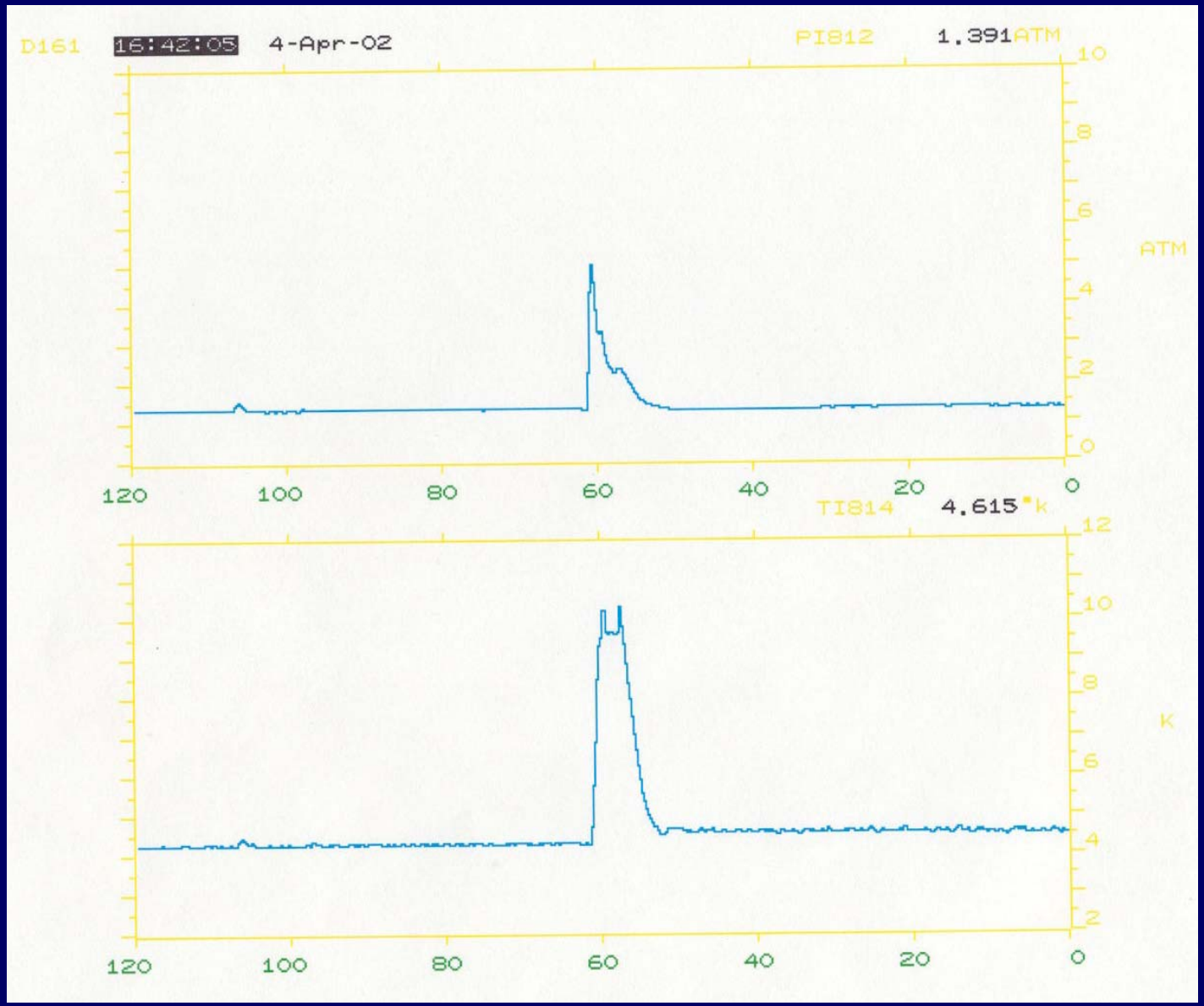
Magnetic Stored Energy and Liquid Helium Boil Off for D2

Quench Current A	Magnetic Stored Energy Kilo-joule	Liquid Helium Boil off Liter
2000	112	50
3000	256	112
4000	448	200
5000	700	312
6000	1008	448
7000	1372	612

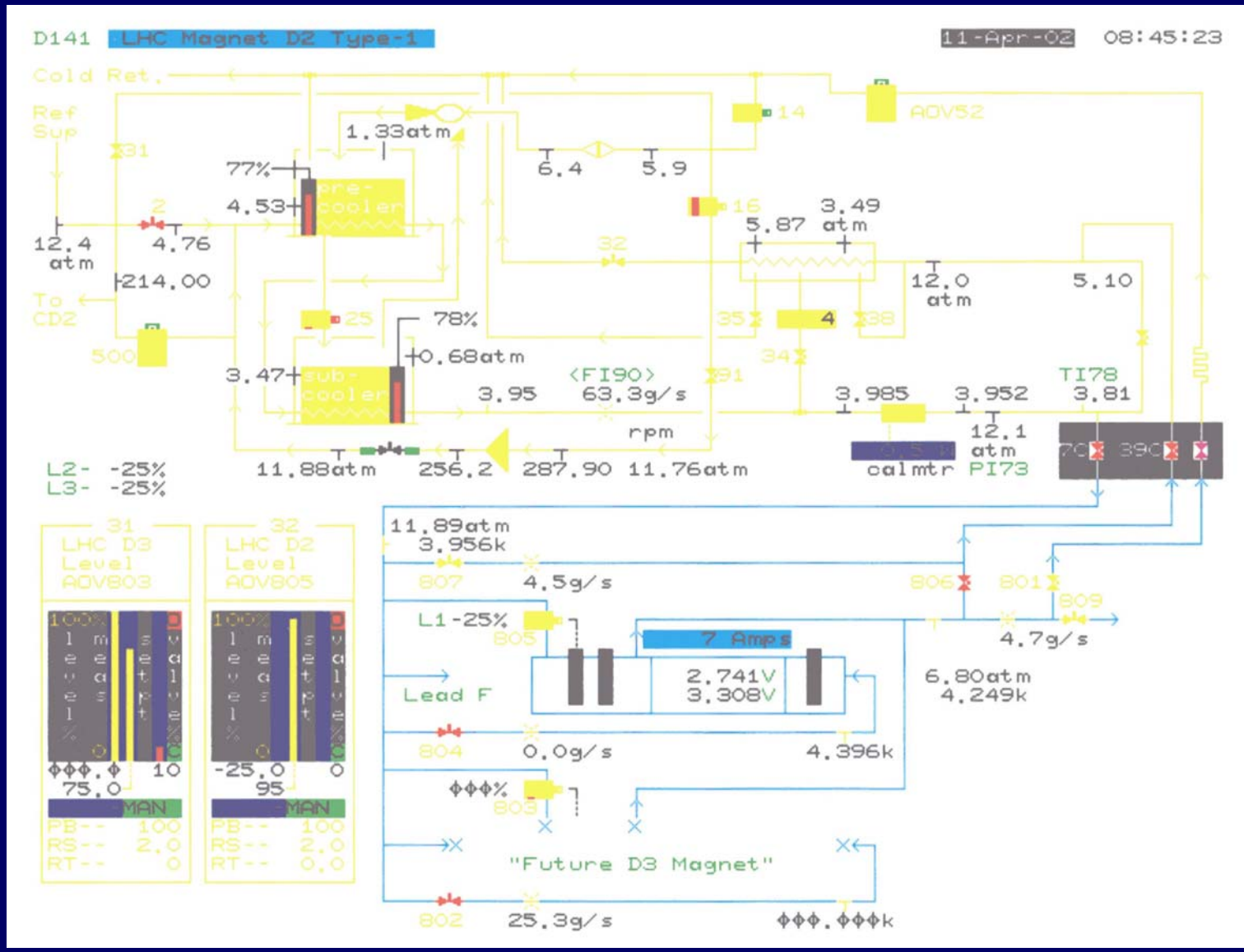
Quench Handling

- Pressure increases rapidly
- Cold helium must be vented immediately after a quench
- With vent valve open, pressure as high as 6 atm was observed
- Temperature in D2 does not increase drastically after a quench and typically in the neighborhood of 12 K
- Demonstrate system safety for magnet quench
- No problem on recovery

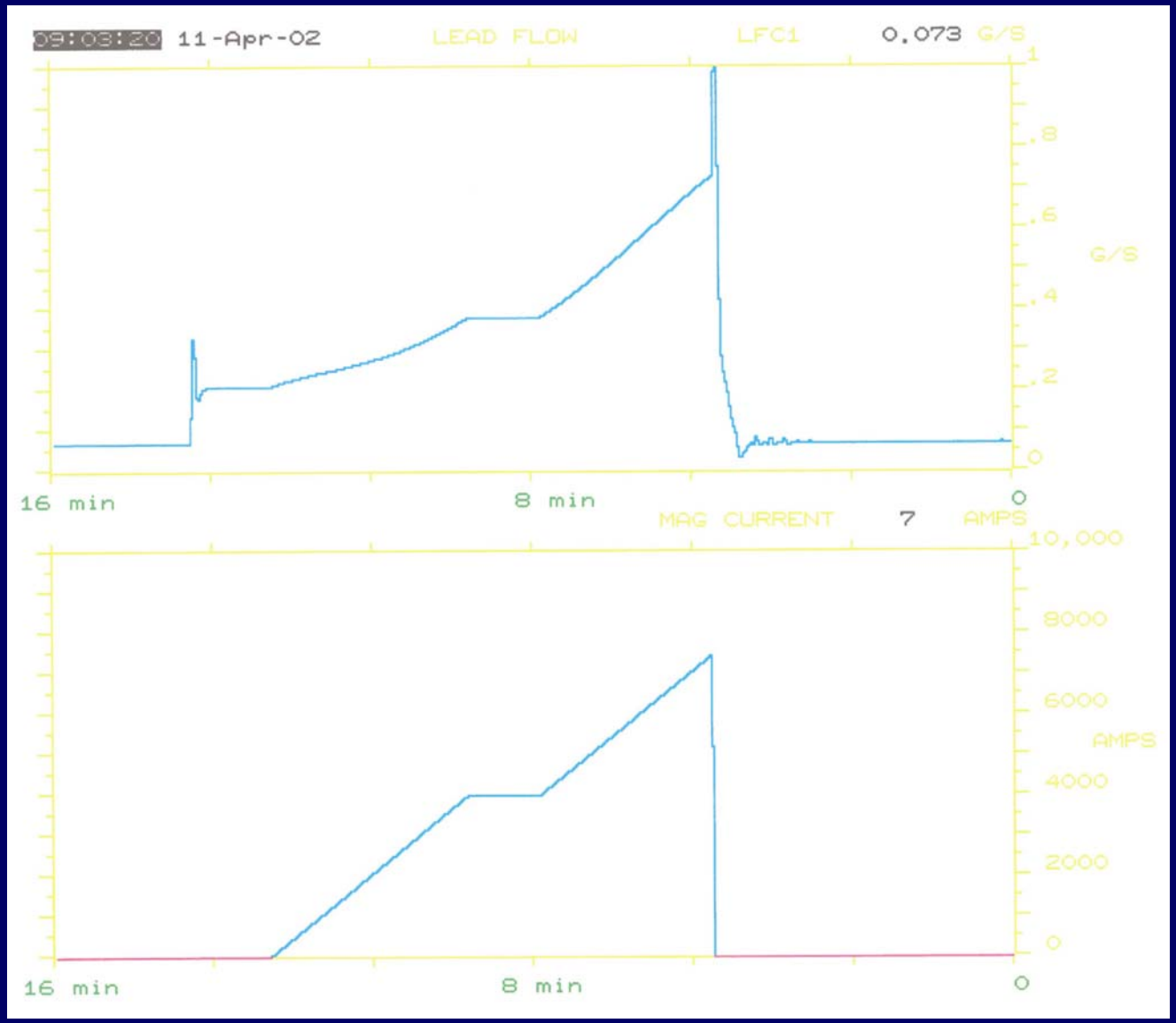
Pressure and temperature after a 6300 A quench for D2



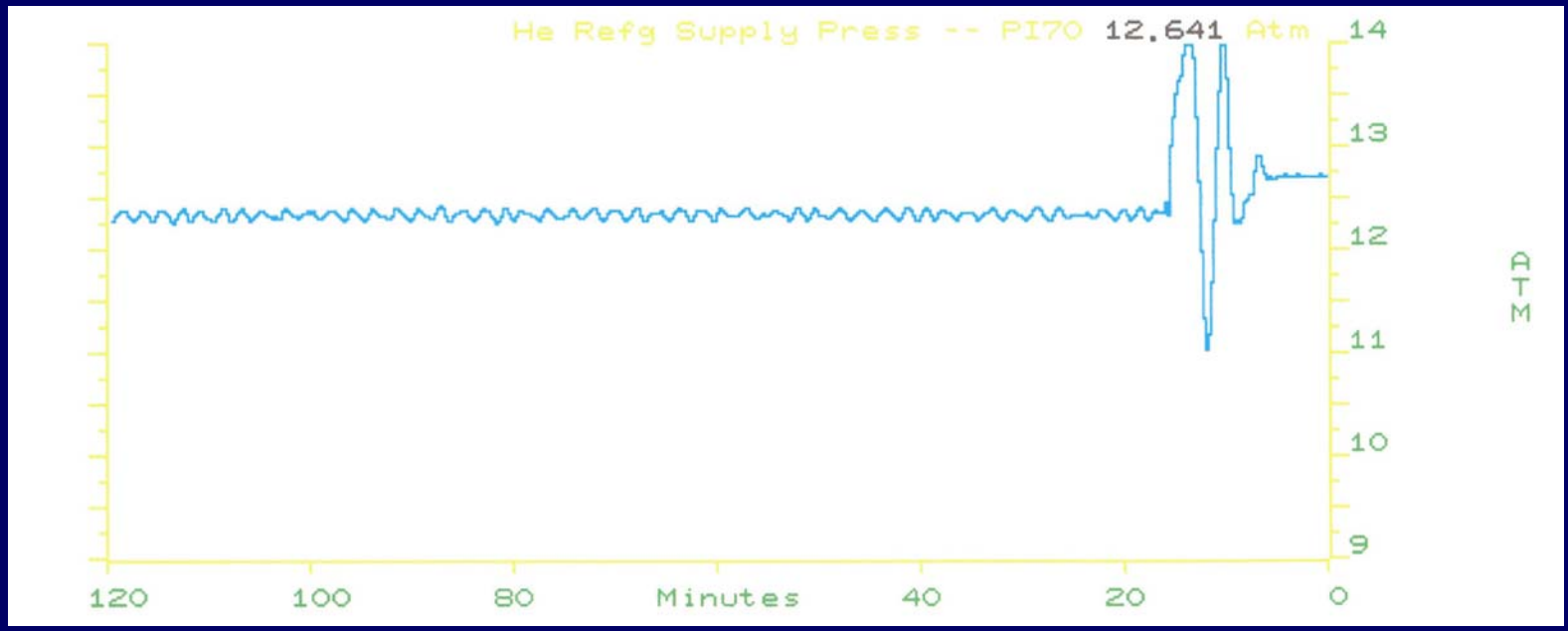
Operating Condition for D2 in Forced Flow Cooling



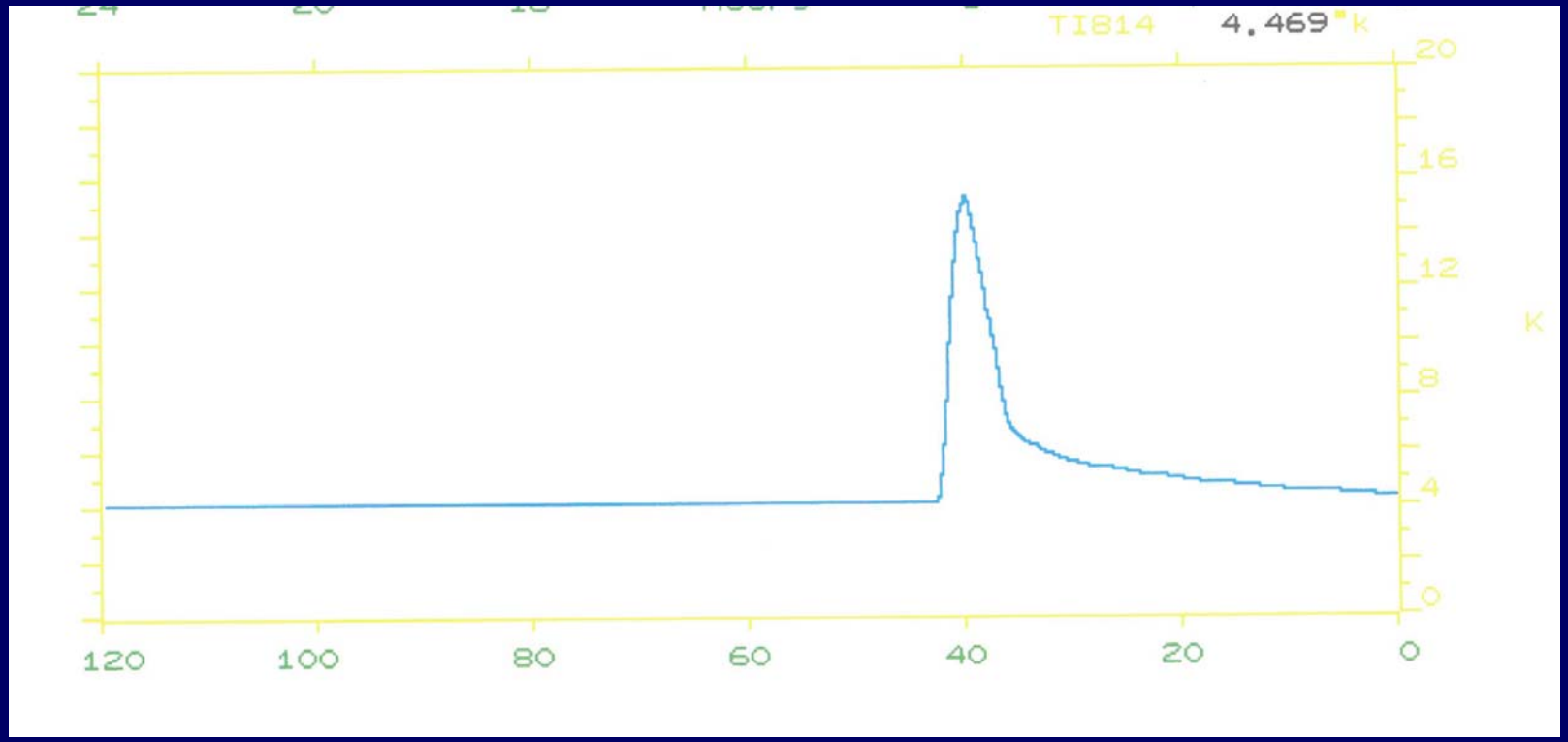
Lead Flow and Current as a Function of Time during Ramping to 7490A



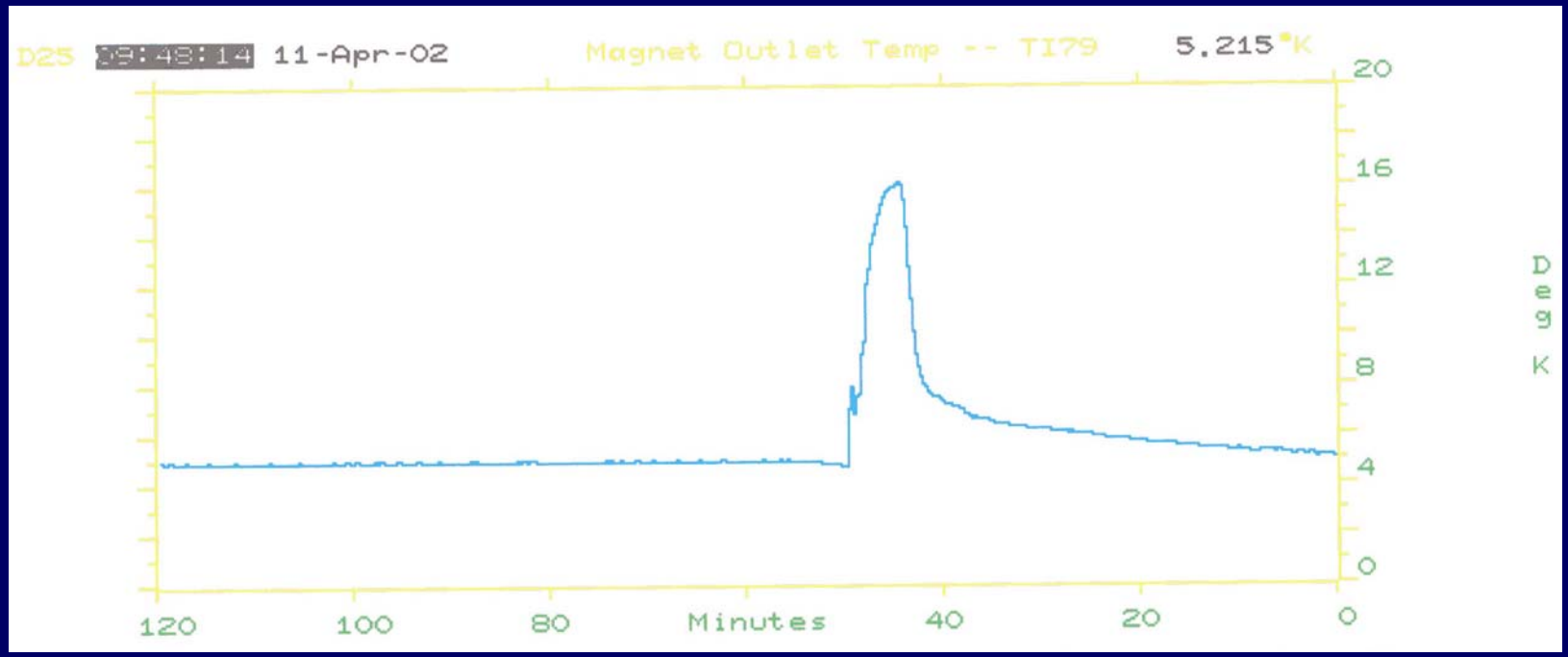
Loop Pressure after D2 Quenched at 7490A – Forced Flow Cooling



Temperature at D2 Return Line after 7490A Quench – Forced Flow Cooling



Temperature at MAGCOOL Return after 7490A Quench – Forced Flow Cooling



Problem Encountered

- Large heat loads from lead pots (no lead flow through the two capped leads for D3) , vent lines are under sized for efficient cooling
- In liquid cool, liquid level in Lead Can shows only if level in D2 exceed 94% above the boil off return line
- High voltage observed in the negative (-) lead, needs ~ 0.15 g/s more lead flow than typical 7500A leads
- Flow controller for + lead failed on 4/18, (+) lead has to be operated manually, (0.25 g/s below 4000A, fully open by-pass valve above 4000A)
- For forced flow cooling, the bus temperature is high 4.8 K and 5.4 K. Larger vent lines will reduce these temperatures and eliminate bus quench.

Summary

- New Feed Can and Liquid Cooling is working
- Behavior of D2 is inconsistent
- Quench current using force flow cooling are higher than that of liquid cooling
- No fundamental problem on Cooldown, Test State, Lead Flow control and Quench handling
- Vent lines on the lead pot need to be enlarged
- Flow controller for D3 leads must be installed to reduce heat conduction
- Implement separate flow control on (-) and (+) leads
- Replace (+) lead flow controller
- Study effect of JT feed and liquid level to the system